PNEUMATIC FOOTBALL KICKING DEVICE BASED ON HUMAN ANATOMY IMITATION


Abstract: Nature has developed several complicated and functional mechanical solutions during evolution of human body. The purpose of this project is to examine whether human anatomy can be imitated accurately and effectively by utilizing pneumatic muscles.

The research platform is a football penalty kick training device, able to perform a penalty kick with adjustable force and direction. The device consists of steel pipe- and beam-based frame, industrial-grade pneumatic actuators and electrically controlled valves. Two fluidic muscles work as a quadriceps and a peroneus muscles, whereas opposing muscular force is created by springs. Raspberry Pi 2 computer is used for controlling and computational operations.

Our study proves that the highly efficient imitation of human anatomy can be achieved by pneumatics.

Keywords: fluidic muscle, sport training device

1. INTRODUCTION

Artificial imitation of human anatomy by robots is often considered to be difficult since human dynamics are very fine and complicated. It is an interesting to study and test, whether human anatomy can be imitated by utilizing modern mechatronic components, such as pneumatic muscles which closely resemble mechanical behavior of human muscle. Until now, human anatomy has been already studied, modelled and mechanically imitated in experimental projects. [1] Although devices have been structurally complicated and accurate, yet very high forces have not been applied in them. For instance, imitating human hand and fingers movement by pneumatic muscles is complicated task, but does not necessarily require high forces or speed. This raises a research problem: can human anatomy imitation be done effectively and accurately by utilizing pneumatic muscles?

Football kick event was selected as a context for artificial imitation since it is a good example of high performance human anatomy execution. Yet it is not reasonable to build a human-like robot with all limbs and similar functional muscles, the construction can be simplified at feasible level. Robots with limbs are developed, but they are far too complex to be used on a field. [2] In this study an experimental robot which is able to perform precise performance footballs penalty kicks in acceptable level of human anatomy is built. Several football shooting machines have been built already, but most of them are based on two spinning wheels which are used to shoot the ball. [3] Adidas has developed the machine where the real shoe is used to shoot the ball as in our machine. [4] Possible outcomes of developing human anatomy artificially may encourage research community to apply human anatomy-alike construction in more demanding applications, such as in field of medical research (i.e. complicated prostheses or body replacements).

2 METHODS

2.1 Mechanical structure

Minimum technical requirements for the device are adjustable and firm mechanical
structure and football launching mechanism which has enough force to deliver a kick similar to human players. Mechanical structure will consist of pneumatically operated beam mechanism, where pneumatic muscles can be applied for generating necessary amount of force and precision. A thigh and ankle mechanisms are operated with pneumatic muscles. Return force in both mechanisms is simply implemented by pull springs, providing opposing force and returning movement. For executing strong and rapid impulse for football, pneumatic circuits and valves of high airflow capabilities are required. Robot must be able to be parametrically adjusted for a precise football shot, which requires adjustable mechanisms at least for a shooting direction and height parameters. Mechanical design was carried out using PTC Creo 2.0. Several concepts were analyzed before the final design. The structure is based on steel beams and pipes which are attached together with bolted joints. All movements are implemented by pneumatic actuators. CAD model of the device is shown in Figure 1. For the bearings Y-bearing plummer block units and polyethylene plates were used. The most important parts of the device are shown in Figure 2 and parts are listed in Table 1.

<table>
<thead>
<tr>
<th>Pos</th>
<th>Description</th>
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<tbody>
<tr>
<td>1</td>
<td>40 mm pneumatic muscle for kicking action</td>
</tr>
<tr>
<td>2</td>
<td>20 mm pneumatic muscle for ankle angle</td>
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<tr>
<td>3</td>
<td>Rodless cylinder for alignment mechanism</td>
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<td>4</td>
<td>Main frame assembly (solid steel beam structure)</td>
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<td>5</td>
<td>Upper frame assembly (steel pipe structure)</td>
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<tr>
<td>6</td>
<td>Leg and ankle assembly</td>
</tr>
<tr>
<td>7</td>
<td>Proportional valve for 40 mm pneumatic muscle</td>
</tr>
<tr>
<td>8</td>
<td>5/3 valves (2 pcs.) for 20 mm pneumatic muscle and rodless cylinder</td>
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<tr>
<td>9</td>
<td>Linear sensor for rodless cylinder</td>
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<tr>
<td>10</td>
<td>Air pressure sensor for 20 mm muscle</td>
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<tr>
<td>11</td>
<td>Air tank</td>
</tr>
<tr>
<td>12</td>
<td>Power source (for 10 V and 24 V outputs)</td>
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<tr>
<td>13</td>
<td>Electronics</td>
</tr>
<tr>
<td>14</td>
<td>Returning springs</td>
</tr>
</tbody>
</table>

Table 1. List of main components

ADAMS multibody dynamics simulation software was used to analyze the most essential dynamics of the machine and define all critical values for the pneumatic components. A screen capture example of the analysis is shown in Figure 3. Required forces were also defined by dynamic analysis.
Final version of the device is shown in Figure 4. During the manufacturing process several changes were made. For example, some solid beams were replaced by pipes due to lighter weight. Also, placement of thigh and 40 mm muscle joint was moved closer to the axle to gain more speed for the kicking movement.

2.2 Pneumatic system

All movements of the device are implemented by pneumatic actuators. Fluidic muscles are used for the kicking movements (kicking action and ankle adjustment). A rodless cylinder turns the upper frame where foot is mounted. This enables the foot to circle around the ball and thus allowing adjustable direction settings. Directional valves do control the kicking direction and proportional valve does control the speed of the kick. A pneumatic diagram is shown in Figure 5.

To maximize the airflow pulse to the main muscle, an air tank was used before the proportional valve. Feeding air directly from the air network is not enough to generate a rapid muscle movement essential for proper operation.

2.3. Control system

Raspberry Pi 2 computer is used for the overall control of the device. Arduino Nano microcontroller receives data from the pressure transmitter and linear drive potentiometer which measure the angle and direction of the foot. Received data is transmitted to the Raspberry Pi over serial connection. Raspberry Pi controls all the valves by its GPIO pins. For the proportional valve, PWM signal defines the control voltage. Control system diagram is shown in Figure 6. All programming was made by C and C++ languages and user can control the device by using command line or GUI. The device also has a front-mounted camera which can be used for defining the direction of the kick.
3. RESULTS
In results section, two main performance values, accuracy and horizontal speed are evaluated. Tests were performed by maintaining air pressure at nominal 6 bar level. For the main pneumatic muscle (paired with a proportional valve) a separate air tank was used to store enough air to be delivered rapidly into the 40 mm muscle. Speed performance was measured by utilizing Photron high-speed camera to record kick events with various ankle angle settings. Even though the proportional valve for main muscle was adjustable with different airflow values, it was always operated at maximum speed since lack of kick performance was apparent all the time. The speed test setup was configured by placing a one meter long ruler in front of the robot, and the high-speed camera on left side of the robot. Figure 7 shows the view captured by the camera. The kick event video clips were captured two times with six different ankle angle positions. As seen in the result diagram, the overall speed varies between 41 - 45 km/h (shown in Figure 8), which is less than half of the goal value set in the beginning (100 km/h), and thus does not reach human performance. The results also indicate that the higher pressure applied in the ankle muscle, the lower is the horizontal speed. This is the result of higher vertical angle of the kick which reduces the horizontal component of speed vector. Horizontal speed can be perceived quite static in general.

Visual inspection also indicates that ankle muscle is flexible and thus works like a shock absorber absorbing kinetic energy. This phenomenon is clearly supported by high speed video recordings. Especially when the ankle muscle is operated with lower pressures (lower kick angles), the muscle is softer and more elastic. Moreover, every time the foot hits the ball, the ankle is suspended a little bit backwards followed by a second major impact which delivers the most of the energy to the ball. This two-phased impact results in unclean kick and thus differs from human kick.
The accuracy test was carried out by performing subsequent football penalty kicks from 10 m distance into a football goal measuring 4 m of width and 2 m of height. Kicks were performed several times into same specific coordinates allowing evaluating mechanical accuracy of the device (maintaining direction and ankle angle adjustments unchanged). Scatter of impact points settled roughly inside a circle with radius of one meter, regardless of ankle angle and direction.

In addition to mechanical accuracy, also accuracy of control systems was evaluated. A laser pointer was mounted in front of the upper frame to help visual evaluation of directional accuracy. Although mechanical tolerances of the device were good (no significant gaps), parametric positioning of measurable pneumatic components (rodless cylinder and ankle muscle) was rather inaccurate and slow. When directional parameters were sent to the robot, the upper frame started oscillating around given location, sometimes for several seconds before setting in position. This was mainly caused by worn and stiff rodless cylinder with high friction. Inaccuracy of directional positioning was slightly compensated by creating smaller and more frequent air pulses to the cylinder when targeted location were close (inside 50 mm range). Rarely did the cylinder reach its dedicated coordinates accurately enough. Occasionally oscillating effect was also present when adjusting the ankle muscle, while ending setting was always precise enough to maintain static angular position.

4. DISCUSSION

Our research problem was to examine if human anatomy can be imitated precisely enough by pneumatic systems to perform a high performance football kick in terms of measurable speed and accuracy. First, it can be noted that human anatomy-based football kicking dynamics were able to be achieved at some level, yet the biggest issue is overall performance and lack of speed. The outcome reflects our hypothesis in a way that human anatomy was able to be reached at least at principle level, such artificially imitated and working dynamics, but did not meet performance goals.

The football kicking device does operate mechanically as expected. For example, dynamics did match our simulation and design of CAD-model, and the robot is able to perform adjustable kicks in different directions with controlled speed. Construction is also very firm with no significant mechanical gaps. Although mechanical accuracy can be considered to be at acceptable level, lack of kicking performance was very evident at all the time. Due to limited airflow into the muscle, or even probably limitations of the muscle performance itself, the device was not able to deliver the ball but only with half of the initial speed as planned. Another important issue in low performance is elastic behavior of pneumatic ankle muscle during the event of impact, where significant amount of kinetic energy is absorbed. High-speed video captures also shows that the impact occurs in two-phased event, dissociating it from human-performed football kick. The placement of the football on artificial grass was also inaccurate at some level, since there was no precise joint point or any kind of tee to support the ball exactly in one permanent location. It was also analyzed whether the profile of shoe could improve the kicking accuracy. In other words, our current foot solution, a 30 mm wide steel pipe does not exactly equal the interaction compared to human foot and shoe, being more narrow, blocky and thus less accurate.

Even though our research goals were not entirely reached, the study does still show that the efficient imitation of human anatomy will be possible to achieve by utilizing pneumatics muscels. By developing and redesigning mechanics, pneumatic and control systems, more optimal result is expected to be achieved with same basic concept.
The football kicking device does operate acceptably enough at principle level. However, achieving human performance needs considerably further refinement and testing. In mechanical point of view the construction of the robot can be considered to be firm and reliable enough to be equipped with more advanced designs and components.

During the project, several new questions were raised and left open to be solved in future; could robot perform considerably better if leg profile or the whole kicking mechanism is built from different design perspective to deliver more energy to the ball? Since our goal of reaching 100 km/h initial speed was not reached, what modifications or equipment is needed to increase the force? One of the key answers might be finding solution to increase pressure and airflow, as well as to study if pneumatic muscles were the bottleneck in performance. Since pneumatic muscles are very strong, could there be any mechanical solutions to increase transmission ratio? How to prevent pneumatic muscle in the ankle mechanism from suspending and absorbing significant amount of kinetic energy, which should be delivered to the ball? One possible option might be revising the ankle mechanism so that the muscle reaches its positions with higher pressure levels. Finally, could the robot or the whole concept of human anatomy imitation be productized for real sport training purposes by equipping it with machine vision and decision making capabilities?

6. ACKNOWLEDGEMENTS
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8. CORRESPONDING ADDRESS
Panu Kiviluoma, D.Sc. (Tech.), Senior University Lecturer
Aalto University School of Engineering
Department of Engineering Design and Production
P.O.Box 14100, 00076 Aalto, Finland
Phone: +358504338661
E-mail: panu.kiviluoma@aalto.fi
http://edp.aalto.fi/en/

9. ADDITIONAL DATA ABOUT AUTHORS
Väisänen, Joni
E-mail: jonii.vaisanen@aalto.fi

Hasu, Olli
E-mail: olli.hasu@aalto.fi

Hevonoja, Toni
E-mail: toni.hevonoja@aalto.fi

Mielonen, Matti
E-mail: matti.mielonen@aalto.fi

Kuosmanen, Petri, D.Sc. (Tech.), Professor
Phone: +358 500 448 481
E-mail: petri.kuosmanen@aalto.fi